論文の内容の要旨

論文題目

Deep Long-Period Earthquakes beneath Volcanoes: Mechanism Analyses and Cooling Magma Model

（火山型深部長周期地震のメカニズム解析と冷却マグマモデル）

氏名

麻生 尚文

Abstract

In the convergence margins like Japan various earthquakes occur. Other than well-known events such as shallow inland earthquakes, interplate earthquakes, and intraslab earthquakes, there are slow earthquakes that relate to slow deformation process. Among them, deep long-period events (DLPs) or low-frequency earthquakes (deep LFEs), which are relatively small earthquakes (M<2) at around 30 km in depth radiating low-frequency seismic waves that are dominant in 2–8 Hz, are best observable seismologically and their seismological study is essentially important to understand the variety of deformation process on the Earth. These events beneath active volcanoes are called volcanic DLPs and those on the plate boundaries are called deep tectonic LFEs. During the last decade, the discipline of deep tectonic LFEs has greatly developed owing to the deployment of the high sensitivity seismograph network "Hi-net" by National Research Institute for Earth Science and Disaster Prevention (NIED) in Japan. On the other hand, volcanic DLPs have been less studied even though they were discovered earlier than deep tectonic LFEs. Especially, the genesis of volcanic DLPs has not been revealed yet along with the difficulty of analyzing noisy signals. In the present study, we first work on the mechanism analyses of volcanic DLPs and then consider a new model for driving force of volcanic DLPs.

Determination of hypocenter distribution and focal mechanisms is essentially important for understanding source process. We therefore work on cluster shapes and source mechanisms at several regions of DLPs in Japan. We obtained fine shape of source clusters in 22 major regions of DLPs in Japan by applying relocation method that improves relative locations among events. Among these regions, 28 clusters were extracted including seven linear clusters and four planar clusters.

Then, we determine source mechanisms at four clusters, where either linear or planar structure is observed. We first develop an inversion method special for volcanic DLPs that have monochromatic waveforms with unclear onsets. We applied this method at four clusters and examined stability tests, but statistically significant results were not observed in most regions. However, compensated linear vector dipole (CLVD) component was not negligible for some events in E. Shimane, where the symmetry axis of the CLVD component is subparallel to the orientation formed by the linear hypocenter distribution. Owing to the development of analyzing much data to extract signal, we have enabled higher level of discussion on mechanisms compared with the previous study on DLPs. The analysis method specialized for DLPs and the statistical perspective of analyzing many events as well as further observations with higher quality would help understanding details of DLPs in the future.

The existence of a driving force such as shear stress or pressure gradient, which is often assumed for shallower LPs, is not necessarily expected at the Moho depth beneath volcanoes. Therefore, I propose the hypothesis that cooling magma produces thermal stress and trigger volcanic DLPs, taking account of their hypocenter distribution. I evaluate the effect by calculating thermal strains for tabular or cylindrical magma intrusions. The produced deviatoric stress is CLVD-like rather than DC-like and can be a reason for the CLVD components observed for some DLPs. Namely, if the thermal stress acts as a driving force of DLPs, we expect a relationship between cluster shape and focal mechanism. Compared with the results of the first half of this thesis, the non-negligible CLVD component in the direction of the lineation formed by hypocenter distribution in E. Shimane can be explained by the relationship expected from the cooling magma model, although the polarity of CLVD is not well determined. The mathematical formulation and calculation enabled quantitative evaluation of the hypothesis in the present study. The thermal strain rate can be comparable with or larger than the direct effect from plate movements. However, for the realistic range of conditions, the thermal strain rate is much smaller than the stress relaxation rate within the cooling magma so that the elastic accumulation of thermal stress seems difficult. In this theoretical modeling, we considered a new possibility of driving force for DLPs, but the limitation of applicable condition and the lack of clear evidence did not necessarily support the model. Further detail evaluation of the applicability together with considering alternative models is important in modeling DLPs.

As a conclusion of the present study, we estimated cluster shapes of DLPs nationwide by source relocation and some of their focal mechanisms by the source inversions tuned specially for volcanic DLPs. Stability tests pointed out insignificance of the inversion results in most regions, but some events in E. Shimane were revealed to have the non-negligible CLVD components whose symmetry axis is sub-parallel to the lineation formed by hypocenter distribution. Then, we considered a new triggering of the volcanic DLPs first in the world. The qualitative relationships between cluster shape and focal mechanism expected from this model are partly consistent with the observation in E. Shimane, while quantitative discussion based on the theoretical calculation infers it is difficult to consider the elastic accumulation of thermal stress under realistic conditions. Throughout this PhD thesis work, we contributed on understanding volcanic DLPs from both observational and theoretical approaches, which is the highest level of quantitative study on DLPs. Following this pioneer study we expect further understanding of DLPs in the future.